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UNITED STATES DEPARTMENT OF AGRICULTURE
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METHYL BROMIDE FUMIGATION OF NURSERY STOCK FOR THE ORIENTAL FRUIT MOTH

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Prior to 1938 several western States imposed quarantines against nursery-stock hosts of the oriental fruit moth (Grapholitha molesta (Busck)), including almond, apple, apricot, cherry, chokecherry, hawthorn, nectarine, peach, pear, plum, quince, and ornamental forms of the same, which prohibited the entry of nursery trees if they originated in areas known to be infested with that insect. In 1937 studies were begun to determine whether methyl bromide fumigation would effectively destroy overwintering larvae of this insect so that nursery hosts might be shipped without risk of disseminating it.

The problem was divided into three phases, (1) the development of lethal fumigation schedules for the insect, (2) a study of the effect of fumigation upon dormant nursery trees, and (3) the development of equipment and methods of procedure for commercial application by nursery companies.

The data concerning the first phase have been published by Johnson et al.[1/] and by Hawkins. [2/]

Following the publication by Hawkins, quarantines of western States were amended in the fall of 1938 to accept nursery trees fumigated with a prescribed dosage schedule of 3.5 lbs/4 hrs. at 70° F.[3/] On the basis of further experimental studies, they were amended again in 1939 to change the prescribed schedule to 3 lbs/4 hrs. at 60°, or 2 lbs/4 hrs. at 70° F.

1/ Johnson, A. C., E. M. Livingstone, and J. W. Bulger, 1942. Methyl bromide fumigation to control oriental fruit moth on dormant nursery stock. Jour. Econ. Ent. 35 (5): 674-677.

2/ Hawkins, Lon A. 1938. Fumigation of dormant deciduous nursery stock for the oriental fruit moth with methyl bromide. U. S. Dept. Agr., Bur. Ent. and Plant Quar. E-458 (processed).

3/ For the sake of conciseness all dosage schedules are abbreviated in symbol form as follows: 3.5 lbs/4 hrs. at 70° F. = 3.5 pounds of methyl bromide for 4 hours at a temperature of 70° F. All dosages are in pounds per 1,000 cubic feet of vault space.

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The results of studies on the effect of fumigation on dormant nursery trees and of the development of equipment and methods of procedure for commercial use are presented herein.

Experimental Studies on the Effect of Fumigation on Dormant Nursery Trees

Concurrently with the studies on larval mortality resulting from fumigation, extensive experiments were conducted to test the reaction of dormant nursery trees to effective fumigation schedules. A majority of these tests were made in Missouri in cooperation with the State Department of Agriculture 4/ and interested nursery companies. Other tests were in cooperation with a nursery company in Maryland, and still others were done at the Beltsville Research Center, Beltsville, Md. These tests were made from 1937 to 1942.

Tolerance of Nursery Trees Except Apple

Two varieties of peach trees were fumigated in New Jersey on February 24, 1937, with a dosage of 3.5 lbs/3 hrs. at 70° F. without injury.

Six varieties of peach, two of cherry, one of pear, six of plum, two of apricot, and one of quince were fumigated in Pike County, Mo., in January 1938. Three dosage schedules were used at 70° F.—3.5 lbs/4 hrs., 4 lbs/4 hrs., and 3 lbs/5 hrs. Only slight tip injury resulted, all in the area normally pruned off at planting time.

Four varieties of peach, four of prune, three of sweet cherry, two of apricot, and two of pear were fumigated in Somerset County, Md., late in March 1938. Dosage schedules of 3 lbs/4 hrs., 3.5 lbs/4 hrs., and 4 lbs/4 hrs. were used, all at 70° F. Tip injury again occurred, but was less in comparable treatments than in the Missouri tests.

Three varieties of peach, one of plum, and one of nectarine were fumigated in Newton County, Mo., on April 4, 1940, with dosage schedules of 3 lbs/4 hrs. at 60° F. and 2 lbs/4 hrs. at 70°. All trees were pruned at planting time and all grew normally.

In 1941, lots of 29 varieties of peach, 4 of apricot, 21 of cherry, 11 of pear, 26 of plum, and 6 of ornamental hosts of the oriental fruit moth were kept under observation following fumigation on January 31 in Pike County, Mo. No injury was apparent, and all trees remaining at the end of the storage period late in April sprouted in a normal manner.

4/ Acknowledgment is made of the considerable assistance given by members of the State Entomologist's Office, particularly Bert O. Brayton, associate entomologist, and J. Carl Dawson, State entomologist (since resigned).

It was concluded from these tests that the dosages used caused no appreciable injury to nursery trees of stone-fruit, pear, and quince varieties.

Tolerance of Nursery Apple Trees

The first tests with apple trees showed them to be injured with the dosage schedules under consideration at that time. Three varieties of apple trees were fumigated in Pike County, Mo., in January 1938, with dosage schedules of 3.5 lbs/4 hrs., 4 lbs/4 hrs., and 3 lbs/5 hrs., all at 70° F. Tip injury was prevalent on all trees, and it was more severe where the last two schedules were applied. A number of trees failed to leaf, and eventually died. These amounted to 11, 34, and 24 percent, respectively, in lots of 110 trees treated with each schedule.

Five varieties of apple trees were fumigated later in Somerset County, Md., in March 1938, with dosage schedules of 3 lbs/4 hrs., 3.5 lbs/4 hrs., and 4 lbs/4 hrs., all at 70° F. In this instance even greater numbers of trees failed to leaf and eventually died, amounting to 18, 62, and 55 percent, respectively.

Tests in the spring of 1940 showed that the lower dosage schedules approved in 1939, of 2 lbs/4 hrs. at 70° F. and 3 lbs/4 hrs. at 60° F., also caused retardation and death of a number of trees. It was found, however, that retardation could be prevented by wetting the trees thoroughly just prior to fumigation. This innovation in procedure was suggested by nurserymen who objected to an apparent drying of the trees during the fumigation period. It was accomplished by drenching the trees with water from a hose or from buckets. In these tests six varieties of apple trees (Golden Delicious, Jonathan, Rome Beauty, Starking, Staymared, and Winesap) were fumigated on April 2 with a schedule of 3 lbs/4 hrs. at 60° F. Twenty trees of each variety were thoroughly wet before fumigation, and a similar number were fumigated without being wetted. Ten trees of each 20 were planted the day following; the other 10 were packed in shipping crates, stored for 2 weeks, then unpacked and planted. Since there were no differences in growth between those planted immediately and those packed and stored, the results are combined. They are given in table 1.

No difference in growth reaction was apparent between lots of trees fumigated with the two dosage schedules. Six varieties of apples were fumigated in both Pike and Newton Counties, Mo., and no differences in growth resulted. All trees in these tests were wet before fumigation. The growth results of the tests in Pike County are given in table 2.

Table 1.--Growth response of wet apple trees compared with unwetted trees following fumigation with methyl bromide on April 2, 1940

Variety	Wet trees	Unwetted trees	Untreated (control)
Golden Delicious	19 N 1 D	13 N 1 R 6 D	20 N
Jonathan	20 N	13 N 7 D	20 N
Rome Beauty	18 N 1 R 1 D	11 N 9 D	20 N
Starking	19 N 1 D	7 N 1 R 12 D	19 N 1 R
Staymared	19 N 1 R	18 N 2 D	20 N
Winesap	18 N 2 D	20 D	20 N
Total	113 N 2 R 5 D	62 N 2 R 56 D	119 N 1 R

N = Normal growth.
R = Retarded growth.
D = Dead.

Table 2.—Growth response of apple trees fumigated with a schedule of 3 lbs/4 hrs. at 60° F. compared with trees fumigated with 2 lbs/4 hrs. at 70°

Variety	3 lbs/4 hrs. at 60°	2 lbs/4 hrs. at 70°	Untreated (control)
Golden Delicious	19 N 1 D	19 N 1 D	19 N 1 D
Jonathan	20 N	20 N	20 N
Rome Beauty	18 N 1 R 1 D	17 N 3 D	20 N
Starking	19 N 1 D	20 N	20 N
Staymared	19 N 1 D	19 N 1 D	20 N
Winesap	18 N 2 D	19 N 1 D	20 N
Total	113 N 1 R 6 D	114 N 6 D	119 N 1 D

N = Normal growth.
R = Retarded growth.
D = Dead.

In studies made during the winter and spring of 1940-41 it was shown that retardation was greatest following treatments in March and April. In these tests the practice of wetting trees prior to fumigation was again shown to be of distinct benefit in preventing retardation. Fumigation and restorage of trees in early winter or midwinter was shown to be practicable. In these tests three apple varieties were used which had shown the greatest retardation in trees not wetted in the tests in 1940. Lots were fumigated in Pike County, Mo., at four dates during the storage period —December 18, January 31, March 21, and April 23. On each date wet trees and trees not wetted were fumigated with the schedules at both 60° and 70° F. Appropriate controls were kept with each lot. The results are given in table 3. Few trees were retarded in lots treated December 18 or January 31, but the numbers

increased considerably in the March 21 and April 23 lots, as shown in the following summary of the number of trees dead or unfoliated at the end of the growing season:

	December 18	January 31	March 21	April 23
Jonathan	0	1	6	10
Starking	2	2	11	3
Winesap	1	2	2	12
Total	3	5	19	25

The few retarded trees in the December and January lots indicated that the retardation was associated with the spring treatments. Of the trees that died in the lots treated in March and April, 14 were wet trees and 30 not wetted, which indicated that wetting prevented the deaths of some trees at that season.

Table 3.--Growth response of trees fumigated at various dates throughout the winter storage season

Treatment	Treated Dec. 18	Treated Jan. 31	Treated Mar. 21	Treated Apr. 23
		JONATHAN		
3 lbs/60° - wet	10 N	10 N	7 N 3 D	9 N 1 D
3 lbs/60° - unwetted	10 N	10 N	9 N 1 D	7 N 3 D
Not treated (check)	10 N	10 N	10 N	10 N
2 lbs/70° - wet	10 N	10 N	9 N 1 D	8 N 1 R 1 D
2 lbs/70° - unwetted	10 N	9 N 1 D	9 N 1 D	6 N 1 R 3 D
Not treated (check)	10 N	10 N	9 N 1 D	10 N
Total of treated trees	40 N	39 N 1 D	34 N 6 D	30 N 2 R 8 D

Table 3.--Continued

Treatment	Treated Dec. 18	Treated Jan. 31	Treated Mar. 21	Treated Apr. 23
		STARKING		
3 lbs/60° - wet	9 N 1 D	9 N 1 R	8 N 2 D	9 N 1 D
3 lbs/60° - unwetted	10 N	9 N 1 R	4 N 6 D	8 N 2 D
Not treated (check)	10 N	10 N	10 N	10 N
2 lbs/70° - wet	10 N	10 N	10 N	10 N
2 lbs/70° - unwetted	9 N 1 R	10 N	7 N 3 D	10 N
Not treated (check)	10 N	10 N	10 N	10 N
Total of treated trees	38 N 1 R 1 D	38 N 2 R	29 N 11 D	37 N 3 D
		WINESAP		
3 lbs/60° - wet	10 N	10 N	9 N 1 D	8 N 2 D
3 lbs/60° - unwetted	9 N 1 D	9 N 1 D	10 N	3 N 7 D
Not treated (check)	10 N	10 N	10 N	10 N
2 lbs/70° - wet	10 N	9 N 1 D	10 N	9 N 1 D
2 lbs/70° - unwetted	10 N	10 N	9 N 1 R	8 N 2 D
Not treated (check)	10 N	10 N	10 N	10 N
Total of treated trees	39 N 1 D	38 N 2 D	38 N 1 R 1 D	28 N 12 D

N = Normal growth.
R = Retarded growth.
D = Dead.

Following the discovery that the retardation of fumigated trees was associated with treatment in the spring season, all the previous work was reviewed. The Maryland tests in 1938 and Missouri tests in 1940 had been made in March or April. The Missouri tests in 1938 had been made late in January, but with higher dosage schedules. In all instances death of a considerable number of trees resulted. Furthermore, it was noted that two types of injury, apparently unrelated, had been recorded, (1) a primary injury confined to tip wood, which appeared soon after fumigation, and (2) a retardation of growth.

The tip injury resulted in the death of the affected portion and apparently did not advance beyond the initial injured area. It was not distinguishable from other tip injury due to storage factors, but it was well shown to have been a result of fumigation in the treatments of 1938, in which the average length of injured tips increased in proportion to an increase in dosage schedule.

Retardation, on the other hand, was not noticeable until the normal trees started leafing. Retarded trees were divided into two groups -- those that leafed out belatedly and soon appeared normal and those that remained leafless. The leafless trees remained alive, as evidenced by the condition of the cambium, until midsummer or later. Occasionally retarded trees appeared in the controls and reacted in the same manner as retarded treated trees.

Since the retardation was distinctly different from the primary injury as evidenced by tip injury, it was concluded that it was caused by drying of the trees during the fumigation operation. Trees are known to be much more susceptible to drying when breaking from dormancy, than when fully dormant, hence the greater amount of retardation that followed spring fumigations was to be expected. The beneficial effect of wetting the trees prior to fumigation during the spring treatments was thus explained.

This point was demonstrated in 1942 in tests at Beltsville, Md., with nursery trees of the variety Winesap fumigated on April 13. Groups of 11 trees each were fumigated (1) after wetting without wrapping, (2) without wetting but wrapped, wholly or partly, with wet burlap and straw, or (3) without either wetting or wrapping. Their reactions were compared with those of similar groups receiving no fumigation but held normally or exposed to a period of drying. The results were as follows:

Fumigated					Untreated	
All wetted but not wrapped	Wholly wrapped but not wetted	Roots wrapped but not wetted	Tops wrapped but not wetted	Neither wetted nor wrapped	Control, normal	Control, dry
11 N	10 N 1 R	10 N 1 R	6 N 4 R 1 U	7 N 2 R 2 U	9 N 1 R 1 U	2 N 4 R 5 U

N = normal, R = retarded, U = unfoliated.

Unfumigated trees which were exposed to drying conditions made a poorer growth response than trees in all fumigated lots, and the reaction and appearance of retarded and unfoliated individual trees were identical with those of retarded or unfoliated trees in the fumigated lots. Trees wet, wholly protected, or with roots protected made the best response, whereas those not wetted and those with the roots or the whole trees unprotected showed more retardation.

From these tests it was concluded that nursery apple trees could be successfully fumigated with dosages of 3 lbs/4 hrs. at 60°, or 2 lbs/4 hrs. at 70° F., provided that the trees were fumigated early in winter or during midwinter, or that all trees were thoroughly wet before fumigation.

Equipment and Methods of Procedure for Commercial Use

A standard design for the fumigation vaults was desired so that approval of individual units by the Western Plant Board would not be complicated. Therefore a design already in use by the Bureau for other purposes was adapted. In this design each unit was lined with sheet metal and the doors and other openings were tightly fitted against molded sponge-rubber gaskets. A combination circulating and exhausting system was provided by a motor-driven blower and a vent which, when open, diverted the gas into the exhaust duct. Provision for heating was required so that the temperature could be maintained at 60° or 70° F. as desired. The insulation of the walls was optional. An adequate duct system to carry the exhausted gas to the outside was also necessary. This design is shown in figure 1.

The fumigation vaults were built by the nursery companies under supervision of their State nursery inspectors. Sizes ranged from 150 to 1,600 cubic feet (figs. 2, 3, and 4). In larger units the trees were loaded on trailers, which were rolled in and out of the fumigation vault (fig. 5). In some eastern States fumigation vaults already approved under the Japanese beetle quarantine were used, since they also conformed to the basic design.

The first fumigation of trees by nursery companies was made concurrently with the earlier experimental studies, in 1938-39, when 10,983 trees were fumigated and certified for shipment in Missouri. In 1939-40 the number of trees increased to 56,554. In 1940-41 and 1941-42 totals of 137,171 and 111,880 trees were fumigated in Missouri alone, and shipments were also made from Ohio, New York, New Jersey, Maryland, Arkansas, Iowa, Kansas, and probably other States.

Based on early experimental studies, fumigation generally excluded apple trees, but by 1942 the numbers of apple trees treated had increased greatly.

In commercial practice the trees are assembled and thoroughly wet down before being placed in the fumigation vault. They may be laid on racks in the vault (fig. 3), or loaded on trailers (fig. 5) which are rolled into the vault. The bulb of the thermometer unit is placed in the center of a bundle of tree roots at the densest point. When the temperature at this point reaches the desired level of 60° or 70° F., the fumigant is introduced. The blower is operated throughout the 4-hour period. At the end of the fumigation period the vault is ventilated and the trees are removed.

Where moderate quantities of trees are to be treated, they are usually assembled as orders and fumigated just prior to shipment. Where large numbers are involved, stocks of many varieties are fumigated and stored in special bins, and orders are filled from these bins.

Summary

Studies of the reaction of dormant nursery trees to fumigation schedules for methyl bromide under the requirements of the oriental fruit moth quarantines of various States were made concurrently with studies of larval mortality, which have been reported elsewhere.

Stone-fruit, pear, and quince varieties showed no appreciable injury from fumigation schedules in tests made at various times from 1937 to 1941.

Nursery apple trees were injured and their growth retarded in tests with high dosage schedules under early quarantine requirements. In later tests with lower dosage schedules it was shown that retardation was greatest following fumigations in March and April, and that wetting trees prior to fumigation prevented, to a large extent, any serious retardation. Tip injury did not occur to any extent with these newer, lower dosage schedules.

It was further found that this growth retardation after fumigation, which occurred more frequently as spring advanced, was indistinguishable from retardation caused when trees are dried by exposure during the period when they break from dormancy. It was concluded, therefore, that

such retardation following fumigation treatments was due to the drying of the nursery trees during the fumigation process. This explained the beneficial effect of wetting the trees prior to fumigation during the spring period.

A standard design of fumigation vault was adapted from one already used for other purposes, and a number of vaults were built by nursery companies, in which thousands of trees were fumigated and shipped under quarantine regulations.

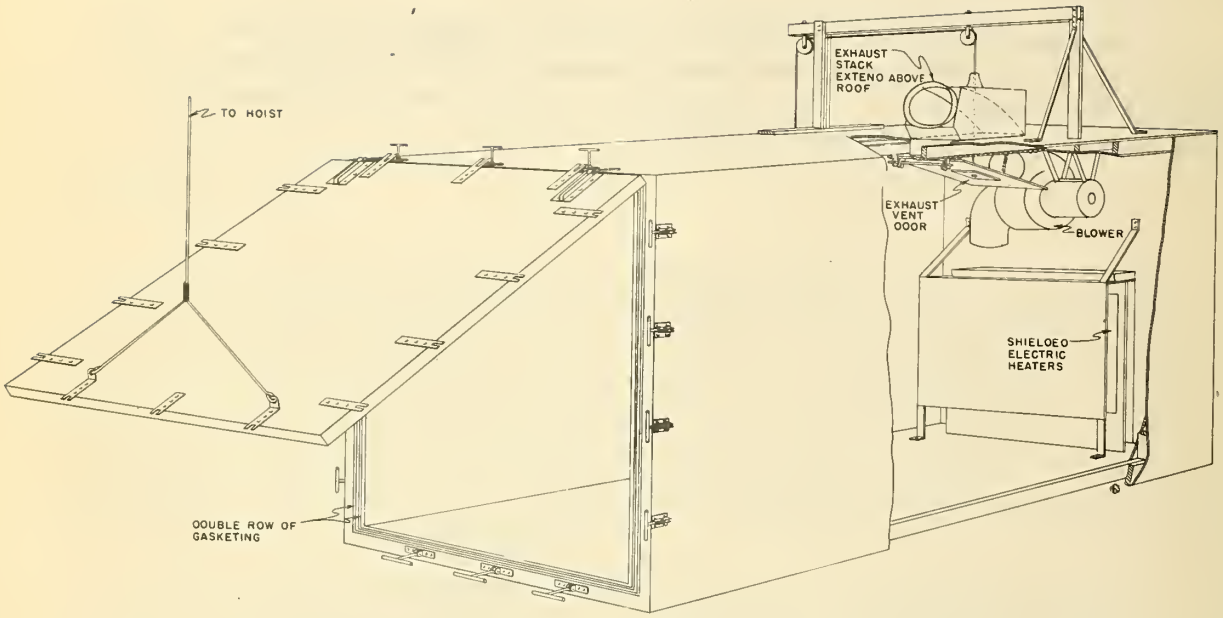

Figure 1.--Design of approved type of methyl bromide fumigation vault.

Figure 2.--Small type of nursery stock fumigation vault of 150 cubic feet capacity.

Figure 3.--Intermediate size of nursery stock fumigation vault of 500 cubic feet capacity.

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Figure 4.--Large type of nursery stock fumigation vault of 1,600 cubic feet capacity.

Figure 5.--Trailer load of nursery trees being moved into a large fumigation vault.